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ALLOCATION OF INSPECTION RESOURCES FOR INTERNATIONAL SAFEGUARDS

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ABSTRACT

Increasing numbers and complexity of facilities inspected by the International Atomic Energy Agency will require difficult decisions about the levels of safeguards to be assigned to materials and facilities should limitations on inspection resources continue. This paper examines some alternative strategies for assigning inspection effort that could improve effectiveness and efficiency of safeguards compared with current inspection practice. These allocation concepts are (1) extension of inspection planning to include material strata and accounting areas that encompass multiple facilities and (2) the use of randomization of the quality and frequency of inspections and inspection activities.

INTRODUCTION

Assignment of inspection resources among facilities inspected by the International Atomic Energy Agency (IAEA) is a complex and important function affecting the quality of these inspections and the safeguards conclusions derived from them. Because of limited resources, however, the IAEA cannot fully attain its safeguards goals, necessitating tradeoffs in the effort assigned to facilities and materials. This report examines some alternative strategies for assigning inspection effort and their potential for improving inspection effectiveness and for reducing inspection costs.

Currently, the IAEA allocates inspection resources and evaluates the effectiveness of the allocation using the individual facility as the focus. Based on negotiated facility attachments, maximum inspection efforts are assigned, some fraction of the effort is actually applied, and safeguards criteria specific for that facility type are employed to evaluate the attainment of safeguards goals. In effect, inspection effort at a particular facility type is assigned independently of other facilities to be inspected. For IAEA safeguards the collection of inspected facilities may be those in a state's fuel cycle, in an operations division's area of responsibility, or all of the facilities under IAEA inspection.

Allocation strategies emphasizing the individual facility preclude the use of global strategies that adapt the resources applied to a facility depending on the other facilities to be inspected. These global strategies incorporate either randomization, which introduces uncertainty in the quality and frequency of inspection procedures, or extension of the scope of inspection planning to include considerations that cross facility boundaries. In either case, the relaxation of constraints on inspection planning results in improved safeguards effectiveness or efficiency.

SAFEGUARDS CRITERIA

An assessment of the utility of a resource allocation strategy should consider consistency with IAEA safeguards inspection practice, attainment of safeguards objectives, and the resources for implementing the required activities. Standards for evaluating these facets of a strategy are implicit in the IAEA's safeguards criteria, which contain a summary of the safeguards objectives, the inspection activities for attaining the objectives, and the required quality and frequency of the activities.

For each facility and material type (direct use, spent fuel, and indirect use) the criteria specify inspection activities in the areas of examination of records and reports, verification of material inventories and flows, and application of containment and surveillance. These activities are graded into four attainment levels according to the quality and timeliness of the inspection effort. Quality of the activity depends on the loss detection sensitivity of a verification method. Timeliness depends on the interval between repetition of the inspection procedures.

The four attainment levels in order of increasing safeguards effectiveness are partial attainment of the quantity component, attainment of the quantity component, almost timely attainment, and timely attainment. The quantity component addresses only the thoroughness of the inspection activity without regard to its timeliness. Attainment of the timeliness criteria is not possible unless the conditions for the quantity component are also attained.

EFFECTIVENESS MEASURES

The rationale for considering alternative strategies for allocating inspection resources is to improve attainment of safeguards goals at no cost increase or to maintain attainment while decreasing costs. Performance measures relevant to these objectives are the effectiveness of the strategy as represented by probability of detecting an anomaly, the cost of the allocation plan, and the consistency of the strategy with current practice.

Effectiveness of an inspection strategy is measured by the attainment of the IAEA criteria in terms of the quality and frequency of the inspection activities. For example, in verifying material inventory, the probability of detecting a defect, which depends on sample size and instrument uncertainty, and the frequency of inventory determine the attainment level. By calculating the attainment level for each facility/material type, one can rank the allocation strategies in terms of effectiveness. Because this ranking is based on IAEA criteria, it incorporates the IAEA safeguards preferences for safeguarding facilities and material, and its evaluation of inspection activities.

Costs of an inspection strategy to the IAEA consist of those incurred at headquarters and in the field. At headquarters, the costs are administrative, such as arranging travel and communicating with states, planning inspections, completing inspection reports, reviewing surveillance film, verifying seal identify and integrity, and training.

In the field, the costs are associated with travel time, implementation of inspections including opening meetings, health and safety procedures, instrument calibration, examination of records, comparison of records and reports, material verification, replacing seals, installing and servicing surveillance equipment, and closing meetings.

Although not directly relevant to IAEA costs, the operator resources and time in preparing for an inspection and in accommodating the inspection procedures by, for example, moving fuel assemblies is an additional cost to consider. Reasons for reducing operator costs are to improve acceptance of safeguards or to permit improved inspections with no increased operator cost.

Consistency of a resource allocation strategy with current Agency practice facilitates implementation of the strategy and avoids the indirect costs associated with changes in Agency procedures and criteria that would be needed to accommodate new strategies not conforming to them.

EXTENDED SCOPE OF ALLOCATION STRATEGY

Relaxing constraints on assignment of inspection effort can increase anomaly detection sensitivity, improve agreement between IAEA priorities for safeguarding material and the assigned inspection effort, and reduce inspection costs.[1-7] The principal constraint on the current disposition of resources is the focus on individual facilities as the basis of planning in which effort is allocated to a facility independently of the other facilities to be inspected. This section describes some alternatives for assigning inspection effort that consider the total collection of facilities to be inspected from a single resource allowance.

Strategies considered are (1) extended stratification in which material verification is based on a single combined stratum encompassing identical material from multiple facilities, (2) the extended materials balance area (MBA) approach incorporating a single MBA that contains multiple facilities, (3) extended material categories in which effort is allocated separately to the direct use, spent fuel, and indirect use categories ignoring facility boundaries, and (4) extended scenario development that considers scenarios involving multiple facilities.

Extended Stratification

Current inspection procedures employ stratification of materials within a facility (for example, fresh, core, and spent fuel strata at a reactor), which has the advantage that where items in a stratum are relatively homogeneous, one gains precision in estimating an attribute of the total population based on a random sample. Extended stratification capitalizes on this effect by expanding a stratum across facility boundaries to obtain the largest possible homogeneous material stratum. A possible example is combining all spent fuel in reactor storage ponds in a state into a single stratum. The extended stratum would be considered as a single entity for development of a sampling plan and assignment of inspection resources.

As an example of the advantage associated with an extended stratum, consider two separate but identical collections of items. Assuming that the differences between operator and inspector measurements on each item are independent and identically distributed normal random variables with variance σ^2, the D statistic (a weighted sum of measurement differences) for each stratum has standard deviation

$$\sigma_D = \frac{N}{\sqrt{n}} \cdot \sigma \quad ,$$

where N is the total number of items in each stratum and n is the sample size.

Assuming a uniform falsification of the item amounts in both strata and setting the decision threshold for detecting falsified data at $2\sigma_D$, there is a 0.75 probability of detecting a simultaneous falsification of amount $2\sigma_D$ in each stratum. However, if the strata are combined, the D statistic for the extended stratum has standard deviation

$$\sigma_{D_{ext}} = \sqrt{\frac{2}{n}} \cdot N \cdot \sigma$$

and the detection probability for the same total falsification of $4\sigma_D$ is 0.88, assuming that the same false alarm rate is maintained.

Extended MBA

Current IAEA accounting procedures are based on MBAs that are contained within a single facility. The extended MBA concept would expand the MBA boundary to encompass all or portions of multiple facilities, for example, the part of a state's fuel cycle containing only low-enriched uranium material.

This concept has been studied in detail in Refs. 1-3 where example fuel cycles were given in which the extended MBA concept was shown to reduce inspection costs since verification of transfers between facilities is not required where these are internal to the MBA. In addition, the extended MBA improves detection sensitivity compared with multiple smaller MBAs, provided the overall false alarm rate is the same in both instances. This effect has a statistical basis similar to that illustrated in the extended stratum example. Of course, the gain in detection sensitivity must be balanced against the loss of ability to localize the cause of an anomalous materials balance to a particular facility.

Extended Material Categories

The concept of extended material strata, in which all material having similar form are aggregated, may be modified to include strata that are composed of the three general material categories (direct use, spent fuel, and indirect use).[5] For example, all direct use material in a state's fuel cycle might be considered as a single stratum for the purpose of assigning inspection effort. This procedure would allow allocation of inspection resources to achieve uniform attainment of the safeguards criteria across all materials in a category without regard to facility boundaries. Because this approach to resource assignment emphasizes material categories rather than facilities, we do not distinguish between material of the same category at different facilities.

We denote the attainment levels for the material categories by the variables A_{DU} for direct use, A_{SF} for spent fuel, and A_{IU} for indirect-use material. These variables take one of the four values--partial attainment, attainment, almost timely, and timely attainment. To each allocation of inspection effort, we associate an attainment triplet (A_{DU}, A_{SF}, A_{IU}) that is a nonquantitative measure of the effectiveness of the allocation.

Consistent with the IAEA priority for safeguarding material categories, we introduce the additional constraint that any inspection allocation should result in attainment levels satisfying

$$A_{DU} \geq A_{SF} \geq A_{IU} \quad . \qquad (1)$$

Within this framework, inspection activities are selected to maximize the attainment levels subject to the constraint (1). Resulting inspection strategies will be fully consistent with IAEA objectives, place greater effort on the more attractive materials, and assure uniform attainment of safeguards objectives for material in the same category.[5]

Extended Scenarios

The IAEA safeguards approach for inspecting a facility is derived from extensive systems studies that consider the potential scenarios for misuse of nuclear material, the anomalies created by these scenarios, and the inspection activities necessary to detect the anomalies. Currently, these analyses do not consider scenarios that cross facility boundaries, neglecting the totality of events necessary to apply material for some use that violates the constraints of a safeguards agreement.

For those states in which all facilities are under safeguards, an alternative analysis would consider scenarios that involve multiple facilities, identifying those key locations within the fuel cycle where inspection activities can best be applied to detect anomalies related to the extended scenarios. By weighting the assignment of inspection effort toward those

key locations that are potentially involved in either more scenarios or in those scenarios with highest consequence, there can be a more effective dispersal of inspection activities.

RANDOMIZATION

Current inspection practice is to repeat inspections of the same type at each facility with the same frequency, intensity, and repertoire of inspection activities. This predictability of inspection procedures allows one to optimize activities for material misuse to avoid detection. However, introduction of uncertainty into execution of inspections offers potential improvements in attainment of safeguards goals either by increasing the probability of anomaly detection or by allowing a potentially broader range of anomalies to be detected.[1,2,8,9]

Among the strategies for incorporating randomization into IAEA inspection practice are the following:

- random selection of the quality and frequency of individual inspection activities at a facility,
- random selection of the frequency of inspections of a given type at a facility,
- random selection of facilities to be inspected from a group of candidate facilities.

Randomization within IAEA Criteria Constraints

Within the framework of the IAEA safeguards criteria, there is sufficient flexibility to accommodate some randomization strategies without reduction in attainment of these criteria. Possibilities for randomization exist for the method of verification of material integrity, the quality of the verification, and the frequency of verification.

For most material strata, the criteria permit a choice of several acceptable verification methods including item counting, serial number checking, variables or attributes nondestructive assay, sealing containers, or surveillance. The specific methods depend on the material type and the facility type.

For each verification method and material type, the criteria specify the quality of the activity in terms of the sample size corresponding to a desired detection probability. The sample size is stated as a lower bound, permitting variations in sample size between the lower bound and complete coverage. In those instances where there are sufficient resources to exceed the minimum required sample sizes, the inspection plan could randomize the intensity of verification across the strata in a facility.

With respect to frequency of verifying materials, the criteria state a maximum interval between verifications that depends on the material type. Within this constraint, the interval between inspections can be varied.

Randomization of Inspection Activities at a Single Facility

Current inspection practice is to repeat essentially the same inspection activities with the same quality at each inspection of a given type. Although this consistency in the inspection plan simplifies the planning and execution of an inspection and the interpretation/analysis of the results, there are disadvantages in that an informed strategy for material misuse can capitalize on the predictability of the inspection. Indeed, by introducing an element of unpredictability into the inspection plan, the inspector complicates the planning of scenarios for material misuse and in some instances increases the effectiveness of the inspection activities at no increase in inspection effort.[8,9]

As an example, consider a facility with two material strata that are to be verified with an attributes measurement for detecting a gross defect in an item. Assume that the strata are identical, each containing 10 items, and that each item contains a significant quantity of material.

The inspector has a total of 15 units of time to complete the inspection, and each item requires 1 unit of time for its measurement. In addition, there is a set-up cost of 5 units associated with the measurement of a stratum, which includes health/safety preparation, instrument calibration, and retrieval of items to be measured.

The interaction between four possible inspection strategies and two possible diversion scenarios for obtaining a significant quantity is shown in Table 1. Clearly, the inspector can guarantee a detection probability of at least 0.2 by choosing strategy 2 or 3 and repeating this procedure at each inspection.

However, randomization of inspection activities offers a substantial improvement over the practice of repeating the same activities at each inspection. In the example, if the inspector chooses strategy 1 with probability 0.5 or strategy 4 with probability 0.5, the overall probability of detecting a material defect becomes 0.5, a substantial improvement over the 0.2 associated with the deterministic strategy.

TABLE 1. Effectiveness of Inspection Strategies for Example Problem

Inspection Strategy	State's Strategies: Divert One Item from Stratum A	State's Strategies: Divert One Item from Stratum B
1 Inspect Stratum A	1.0	0
2 Inspect Strata A & B	0.3	0.2
3 Inspect Strata A & B	0.2	0.3
4 Inspect Stratum B	0	1.0

Randomization of Inspection Frequency

Randomization of the frequency of inspections at a particular facility is constrained by required notification of facilities prior to a visit to arrange operational prerequisites such as opening a reactor core. Thus, although completely unannounced inspections are not generally practical, randomization of visits within a prearranged schedule of potential inspection dates is possible.

The conformance of this strategy to the IAEA criteria for evaluating inspection effectiveness depends on the type of inspection that is randomized. If physical inventory inspections are randomized, then the quantity component of the criteria is probably not attained since this requires some minimum number of physical inventory verifications annually. However, if only interim inspections are randomized, then the quantity component may still be attained, but no attainment of the timeliness component is possible.

Clearly, reductions in inspection resources are realized for those inspections not carried out. Alternatively, this strategy can increase effectiveness when the resources from inspections not implemented are applied to increase coverage at the inspected facilities.

Randomization Over Facilities

The concept of randomization over facilities consists of selecting from a collection of facilities, such as those in a state's fuel cycle, a random sample for inspection over a time period such as 1 year. Under this strategy, the resources not applied at the uninspected facilities either could be applied to increase the effort at the inspected facilities or could be withheld to achieve resource savings.

For those facilities not inspected, the safeguards criteria would not be attained and no statement would be possible about the safeguards status of the material at the facility.

A further practical difficulty is the random fluctuation in the number of each type of facility to be inspected, which might require that all inspectors be designated and trained in the inspection of all facilities, a condition that is probably not achievable.

TABLE 2. Summary of Selected Strategies for Inspection Resource Allocation

	Consistent with IAEA Criteria	Improved Effectiveness	Reduced Inspection Cost
Extended strata	*	Yes	*
Extended MBA	No	Yes	Yes
Randomization of inspection activities	*	Yes	*
Randomization of facilities	No	*	*

*Depends on details of implementation.

SUMMARY

Although the concepts of extended scope of inspection planning and randomization of inspection activities appear to offer improvements in the effectiveness and efficiency of international safeguards, a complete evaluation of their usefulness requires a study to quantify conformance with IAEA safeguards criteria, effectiveness in terms of probability of detecting anomalies, and cost reduction. However, based on the qualitative considerations discussed in this report some general conclusions about a few of these concepts are summarized in Table 2.

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